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ABSTRACT

An argument is made in this document for the development and testing of Computer Aided Instruction teaching models that are prescriptive as well as descriptive. It is felt that a Computer Aided Instruction system is needed more as a "Theory Machine" and a "Laboratory" than as an instrument for implementation. As the communication between the human teacher and student does not proceed in accordance with any one standardized set of rules, it is felt that the computer system must be programed in such a manner that its teaching strategies may be varied to adapt to individual student response modes. One research problem which is explored is the identification of useful variables to include in both the "if" and "then" statements of teaching rules. A study is described which examines the consequences of using a particular rule of adaptive instruction. Charts, sample frames, and references are included. (SH)

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COMPUTER AIDED INSTRUCTION - THEORY AND PRACTICE

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AUTOMAZIONE NELLA EDUCAZIONE

AUTOMATION AND EDUCATIONAL PROBLEMS

Atti del Convegno Internazionale dell'Automazione nell'Educazione tenutosi a Milano dal 25 al 26 novembre 1968 sotto il patrocinio della Fondazione per lo Sviluppo e la Diffusione delle Istruzione e della Cultura Scientifica e Tecnica (FOIST)

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il Saggiatore
di Alberto Mondadori
Editore

COMPUTER AIDED INSTRUCTION - THEORY AND PRACTICE [1]

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Riassunto *L'elaboratore digitale è un utensile importante per spiegare e condurre il processo educativo. Oggi è molto utile per sviluppare concetti definiti e collaudabili dell'istruzione, ma in pratica è usato maggiormente per completare l'istruzione. Il contributo potenziale di un sistema CAI come catalizzatore nel processo di dar forma all'istruzione ed in quello di analisi della validità dei concetti dell'istruzione è stato sottovalutato.*

Si discute sullo sviluppo e sull'analisi di modelli per l'insegnamento che sono atti a prescrivere oltre che a descrivere. La forma piú utile di descrizione da usare per le regole di istruzione è l'espressione delle eventualità. Vengono riuniti gruppi di regole per definire le strategie di insegnamento. L'identificazione di variabili utili per includere sia l'espressione «se» che «allora» delle regole di insegnamento è un urgente problema di ricerca. Basandosi su una ricerca precedente il modello ideografico usa variabili concernenti le caratteristiche dello studente come una componente dell'espressione «se». Dal compito dell'apprendere deriva un'altra componente. Vengono descritti cinque modi di istruzione per l'espressione «allora». Per ogni modo devono essere determinate chiare variazioni.

In questa relazione è brevemente descritto uno dei nostri studi per illustrare un approccio per lo sviluppo del sistema CAI basato sul

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modello ideografico e che si avvale della reazione dello studente per prendere delle decisioni. Questo studio si serviva inoltre di una strategia adattabile per poter dare agli studenti un nuovo ambiente simbolico per imparare a prendere delle decisioni; i dati ottenuti mostrarono che senza una esplicita istruzione gli studenti imparavano a prendere delle decisioni ad un livello subottimale. Vengono fatte delle raccomandazioni per questa correzione suggerendo l'impiego di un approccio multiforme.
Per ultimo, vengono descritti metodi di programmazione per l'impiego di un sistema CAI in modo da sviluppare le capacità di imparare come imparare.

Abstract *The digital computer is a significant tool for explicating and guiding the instructional process. Today it is most useful to develop formalized and testable conceptions of instruction, but in practice it is being used more to implement instruction. The potential contribution of a CAI system as a catalyst in the process of formalizing instruction and in testing the validity of conceptions of instruction has been underestimated.*
An argument is made for the development and testing of teaching models that are prescriptive as well as descriptive. The most useful form of description to be used for the rules of instruction is the contingency statement. Sets of rules are combined to define teaching strategies. An urgent research problem is the identification of useful variables to include in both the «if» and «then» statements of teaching rules. Based upon previous research, the idiographic model uses variables relating to student characteristics as one component of useful «if» statements. Another component comes from the learning task. Five modes of instruction are described for the «then» statement. Within each of these modes explicit variations need to be determined. One of our studies is briefly described in this paper to illustrate an approach to the development of a CAI system based upon the idiographic model and using student response data to make decisions. This study also used an adaptive strategy to provide student with a new symbolic environment for learning to make decisions; the data obtained showed that without explicit instruction students learn to

make decision at a suboptimal level. Recommendations are made for rectifying this by using a multi-mode approach. Finally, programming methods are described for using a CAI system in ways intended to develop learning-how-to-learn skills.

The digital computer, when used in instruction, is a symbol-processing device capable of performing well-defined, albeit complex, processing. Therefore, any teaching strategy that can be explicitly represented as the manipulation and transformation of symbolically represented information can be implemented by a computer-based instructional system. The first task of the teacher or educational theorist is to reduce the strategy to an explicit formula so that it can be programmed for implementation by a computer-assisted instruction (CAI) system.

In the behavioral sciences, particularly in the psychology of teaching, the use of a computer for instruction is a significant development. This is not because of any financial savings that might ultimately accrue but because of its immediate contribution to the clarification of teaching as a set of dynamic processes. As contrasted with the already highly formalized areas of mathematics and engineering, teaching needs explication more than efficient implementation; therefore a CAI system is needed more as a «theory machine» and a «laboratory» than as an instrument for implementation. These labels need some explanation, for they identify a kind of computer usage which is very different from the predominant way a computer is used in more highly formalized areas.

The Explication of Theory and Practice

In CAI a computer is used to explicate theory and to define effective practice. This means that any teaching theory that is used to develop a CAI program must be formalized. This process has several clearly defined steps. One set relates to the method or logic of instruction; the other set to the content. The steps in the first set are as follows. First, the events must be defined. Second, the time sequences must

be specified completely so the event structure is mapped. This is typically done as a flow chart. In developing CAI materials for use with students, a set of behavioral objectives must be developed and then an explicit description of the task must be accomplished so that the subject matter elements and relationships are specified. The computer language used to code the material and to control the teaching process as it is performed by a CAI system represents the complete description of the process of interaction between a student and a teaching system. Together with the content that is presented to the student and expected from the student it constitutes an instructional program.

An instructional program in this form is more complete and requires a more detailed analysis than a script or ETV presentation or a fully prepared classroom lecture.[1] The major factor in the difference is the elaboration of the processing of student response. In the CAI context a teaching system is a broad concept indeed. It includes student interaction with a variety of media – audio tapes and photographic images as well as text – and the use of different modes of instruction at different times in the teaching process, depending upon the student's performance. Unlike a film, ETV or lecture, CAI is a response-dependent teaching system.

The process of achieving a cybernetic interaction with a computer and a student differs also from the interaction involved in the use of other media. A distinctive difference is that the interaction must be planned and materials prepared in sufficient detail with respect to both the logic of its organization and the processing instructions that permit it to be run on a computer. While it may appear to be trivial that it must be coded in a language which a computer can use, there are significant implications of this process. Unlike natural languages, which are permeated with connotative ambiguities, computer languages are denotative. Therefore, a description of teaching in a computer language is less equivocal than one in natural language; furthermore, the computer program must be complete and accurate

[1] It is interesting to note at this point in time that the cost to prepare an hour of CAI is *less* than that required to produce an hour of film or ETV.

or the system will not run. These are important internal criteria determining the sufficiency of the description of the teaching that is to be accomplished by a CAI system.

The formalizing process for CAI material has other important implications; of significance are those relating to the development of models of instructional processes. The models used must be made operational; they are translated into action. Not only are they demonstrated in a form that can be observed repeatedly, for review and independent analysis. Furthermore, a protocol of the student's interaction with the system is recorded and provides the most complete record of instructional interaction that is available. These protocols are raw data for either immediate or later analysis, and thus can serve as a data base for both inferring the nature of the learning process and diagnosing difficulties with the teaching strategy.

Third, instructional material which has been used to teach students on a CAI system has gone through the important step of verification. The first criterion to be met by any teaching strategy for CAI is that the program to implement it runs on a system. This is a more rigorous criterion than any others used to verify the teaching strategies developed for other means of instruction.

A CAI system also makes it possible, as well as convenient, to validate the teaching model used in developing an instructional program. The same system can be used for both verification and validation. This may sound trivial but, when placed in the context of the history and current status of instructional research and theory, it is a very significant factor. Related is the fact that a CAI system makes the complex series of events in a student-system interaction replicable with a high degree of reliability. In fact, the reliability level is higher than for any other approach to the study of teaching or to the use of teaching concepts. This is critical, not only for meaningful research on instruction and training, but also for routine teaching in a school or training establishment where reliable results are needed. Replicability, the controlled manipulation of variables, and the precise validation of teaching conceptions has only been possible with the development of CAI systems. The history of earlier attempts to study teaching is a record of partially described procedures leading to ambi-

guous results. More than anything else, the potential for useful research on teaching supports the argument for using computers to determine the effectiveness of alternative instructional strategies and, ultimately, develop a useful and effective theory of teaching.

It should be mentioned that no attempt is being made to argue for the computer as a way to model the complex brain processes of teachers. In fact, this paper tries to do something very different. It treats the computer-based teaching system as an instructional resource, not as a model of a teacher. It is more the model of a process than of a person. CAI is more like a teaching team than an individual teacher, hence the words, «instructional system.» CAI is not simply programmed instruction on a computer. A computer-based teaching system can do more than an unaided teacher; however, the teacher may be a significant element in an instructional environment that uses a CAI system (Stolurow,1965 a). A computer-based teaching system may be a part of a larger process involving a comprehensive manipulation of the cognitive, affective and motoric environment. Many past attempts to model the teaching process have ended with a flow chart. As such they are merely descriptive analyses at a very general level (e.g., Gage, 1963) of a method, strategy, of tactic of instruction. In developing CAI materials, on the other hand, this is where the process begins. Far more critical to our understanding of the instructional process is the subsequent step of translating the flow chart into an operational program that is a dynamic interaction with a student. This latter step imposes important constraints upon the conception of an instructional process, which frequently produce both significant refinements and necessary definitions. The translation of a conception into a set of instructions for a computer must be explicit. Typically, theories of teaching have not been response sensitive nor sufficiently developed to cover various courses of action. It is precisely at this point that the implications of the process of verification become significant. A critical test of a theory is its internal consistency; another is its ability to account for the available data. A third is the test of its utility, its ease of translation into action and including the development of useful prescriptive implications. It is necessary to translate a conception into a set of opera-

tions, and in the case of teaching this means a guide for the manipulation of a learning environment, e.g., the sequence in which information is presented.

Validation is the step in which data are collected to demonstrate that the procedure for student-system interaction is capable of altering the behavior of students in specified ways. With most instructional systems, teachers are a part of the system and both the student and the system are expected to change as a result of the interaction. While the student is to modify his behavior in accordance with the objectives of the course, the system is also to learn about the student (e.g., Pask, 1960; Smallwood, 1962; Stolurow, 1965 b, a) so as to produce the change in the optimum way.

The final step is optimization. Here the purpose is to determine which model of teaching to use. Several criteria are involved. One is economy or efficiency in terms of system requirements for processing interactions; it is the optimization of its internal processing as judged by operational criteria. Another is optimization of the changes produced in the student; a third is the optimization of changes in the system of teaching.

Modeling and Models

In modeling of any kind, it is useful to distinguish description from prediction. Some models are designed for one and not the other, and some are designed for both (e.g., Stolurow, 1965 a). Basically, this distinction refers to the purpose of the model which may be to characterize either the means or the end of a process.

In descriptive modeling, the purpose is mainly representation and, therefore, hypothetical constructs are used as theoretical devices. In predictive modeling the purpose is to maximize the information that can be provided about the future state of a process, and intervening variables are used (McCorquodale and Meehl, 1948; Marx, 1951; Ginsberg, 1954; Maze, 1954). Modeling for different purposes is to meet different requirements. For example, it is not necessary in a predictive model to specify relationships between and among all the elements in a complex process. Rather, one minimizes the infor-

mation used and deals with only the amount of information necessary to specify a function that transforms an input into a verifiable output. In descriptive models, on the other hand, if the primary purpose is to represent a static set of relationships, a dynamic set, or a process, in terms of its critical properties, it is not necessary to predict a particular external event. Basically, modeling is a process of differentiating the critical from the non-critical features in a complex system, and of characterizing the critical elements and relationships for a specified purpose. Intervening variables are one type of symbolic device used in modeling. They are abstractions, frequently mathematical formulas, that permit one to map a set of inputs on a set of outputs in a dynamic system or to transform a static one. However, not all predictive models use abstract symbolic devices. An ordinary watch, for example, is a concrete model used for prediction, but it is not at all descriptive of the external event structure it predicts. An orrery, on the other hand, is a concrete model that describes the position of the planets in relation to one another, but it does not predict them or measure time.

Many predictive models use intervening variables to achieve their primary purpose, identifying a future state of a system. In the behavioral sciences, the mathematical models of learning are examples (e.g., Bush and Estes, 1959! Atkinson, Bower and Crothers, 1965), of predictive models that use intervening variables. The equations they use do not contain elements or operators that correspond in a one-to-one manner with observables, e.g., Bush and Sternberg's (1959) single operator linear model in which the states are values of response probabilities that have to be estimated from group data.

Models of Teaching

Modeling the teaching process is difficult not only because we know so little about it, but also because it has been so difficult to get sufficient replicability of a particular type of teaching behavior in order to characterize it. Furthermore, the usual means of observation are not highly reliable with respect to critical variables. There are a

few descriptive models of teaching, a few predictive models (Gage, 1963), but very few cybernetic models. Cybernetic models require a fine grain analysis of the teaching process; they use as the object of inquiry the dialogue between student and system.
A model of teaching must be *descriptive* if teachers are going to use it. It must be *prescriptive* if it is going to be used for decision-making. It also must be cybernetic, or response sensitive, if it is adaptive. A model for adaptive, or personalized, instruction specifies a set of response-dependent rules to be used by a teacher, or a teaching system, in making decisions about the nature of the subsequent events to be used in teaching a student. The efforts to develop multiple-stage decision models of teaching have not been extensive, nor are the few that exist very old. Consequently, the kinds of data needed to support and extend them are almost non-existent. At the present time, they represent a beginning set of hypotheses about the teaching process.

Some Decision Models

Carroll (1962; 1963) evolved a model of school learning that has implications for teaching. This model could be developed for use in a computer-based instructional system, although Carroll did not do so (Carroll, 1963; 1965). Carroll's position is relevant, however. He says, «What is needed is a schematic design or conceptual model of factors affecting success in school learning and of the way they interact» (Carroll, 1963). To be useful to education, the model needs to include both learner and instructional variables. «Aptitudes» and «ability to understand instruction» are basic characteristics of the learner, and «quality of instruction» summarizes the performance of a teacher and the caracteristics of textbooks, workbooks, films and teaching machine programs. Unfortunately, although his model does embrace both sets of variables, it is a static model, because it uses data to make a prediction about the level of success a student will achieve at the end of a period of instruction. It does not include rules for making adjustments in the quality of instruction while students are learning; it is not a guide for action while teaching.

Carroll says that the primary measure of aptitude is the time the individual needs to learn a task. The aptitudes are specific to the task and are measured by appropriate tests. He identifies time measures as critical dependent variables in school learning, and distinguishes between the time a person needs to spend, the time he actually spends «paying attention» and «trying to learn», and «time allowed for learning» («opportunity»).

Gagne's model (1965),[1] on the other hand, is descriptive. He describes the process of producing learning effects in terms of decisions and he has compiled a list of six types of decisions. Three are related to planning for learning: (*a*) decisions defining objectives; (*b*) decisions determining the learning structure; and (*c*) decisions about motivation; and three are concerned with instruction: (*a*) decisions about the conditions for learning; (*b*) decisions that provide for knowledge transfer; and (*c*) decisions that relate to the assessment of the capabilities that have been learned. However, Gagné has not developed an articulated model; he has preferred to formulate the classes of critical events in the socio-economic context of instruction. For example, he says:

«Many people besides the teacher now make decisions about learning objectives... the structure of knowledge to be imparted is determined by the writer of a textbook or a workbook, or by the designer of a film, as are also many of the conditions of learning. Although they may be influenced by the teacher's decisions, the conditions affecting transfer of knowledge are often constrained by custom, avail-ability of space and other logistic matters.» (p. 264).

Obviously, Gagné's model of teaching, while addressed to the critical problems of instruction, is not designed to deal with the mechanisms that determine step-by-step decisions governing adaptive instruction.

A Norm Referenced Adaptive Model

When a computer is used to model the teaching process, it is ne-

[1] Gagné also has a learning model which conceives onf school learning as a one-way progression from simple to increasingly complex learning. The analysis of learning tasks for each subject matter is a hierarchy.

cessary to identify the separate functions that must be performed and the sequence in which they are to be accomplished. Usually, a flow diagram and then a listing is prepared. The next step is to put the analysis to work by seeing whether a system actually can be developed to go through the steps. This requires translation of the analysis into a computer language, a coding process.

Smallwood (1962) developed a mathematical model for use in computer-based instructional systems. It differs from Carroll's and Gagné's in that it treats variables dynamically – as a set interacting in time.

Smallwood makes the assumption that the instructional system should be adaptable to the student: the system should learn about the student as the student learns about the course material. He has the system collect and use information which makes it possible to alter the bases for decisions and he uses the data obtained from all students to re-estimate the parameters employed in making instructional decisions as the system teaches.

Smallwood views a teaching program as a branching network of blocks which extend through a series of different levels of instruction. Each block contains enough information to advance instruction one or more levels.

The model uses two kinds of measures: (*a*) measures of performance, and (*b*) criterion measures of the effectiveness of the instruction. The performance measures consist of estimates of probabilities, i.e., the probability of a student with a known response history on a preceding block making a particular multiple choice response. Probability is defined as the fraction of students out of an infinite population with identical response histories who will select the same alternative.

Smallwood succeeded in demonstrating that his model can produce different paths for different students. He also obtained some evidence indicating that the decision rule itself can change as more data are used to estimate the parameters of the model. However, he mentions that «we have not even proved that the changes mentioned above are changes for the better» (Smallwood, 1962, p. 103).

An Idiographic Programming Model

Another instructional system that was designed and built to provide an organizing capability was SOCRATES (Stolurow, 1966). The model used to design the CAI system was called the idiographic programming model (Stolurow, 1965 a, b, c). This model states that a computer can be used to control instruction in a dynamic interactive process through (*a*) the presentation of information and question frames; (*b*) the presentation of various forms of evaluative feedback; (*c*) the discriminative processing of responses; and (*d*) the recording of student performance data. At each decision point, a discrete contingency statement, or teaching rule, is used to select (*a*) the next frame; (*b*) the length of its exposure; (*c*) the information feedback; and (*d*) the evaluative feedback. These rules are stored in the computer and automatically applied in the selection of every frame or block of material for each student (e.g., Merrill and Stolurow, 1966; Lippert, 1967) as he responds.

The basic processes with which a model concerns itself determine its scope. In the idiographic model the decision process is divided into three different stages: (*a*) pretutorial; (*b*) tutorial; and (*c*) administrative. The first is the set of decisions made to initialize the instructional process and to determine the first teaching strategy to use with a student. Once the process begins the strategy used with a particular student is monitored to determine whether or not it should be changed.

Strategy can be thought of as a set of rules in such a way that the combination of the rules used and the subject matter manipulated is called a teaching program (Stolurow and Davis, 1965).

A second level of system design is involved when the set of rules which determine a student's program is changed. At this level, sets of rules are contingencies instead of events (i.e., those involved in performing the teaching functions). As conceived by the idiographic model, the pretutorial and tutorial processes are presented in Figg. 1 and 2. The second figure also presents some of the administrative functions. The tutorial process in this model is cybernetic because the student's responses determine the nature and sequence of the

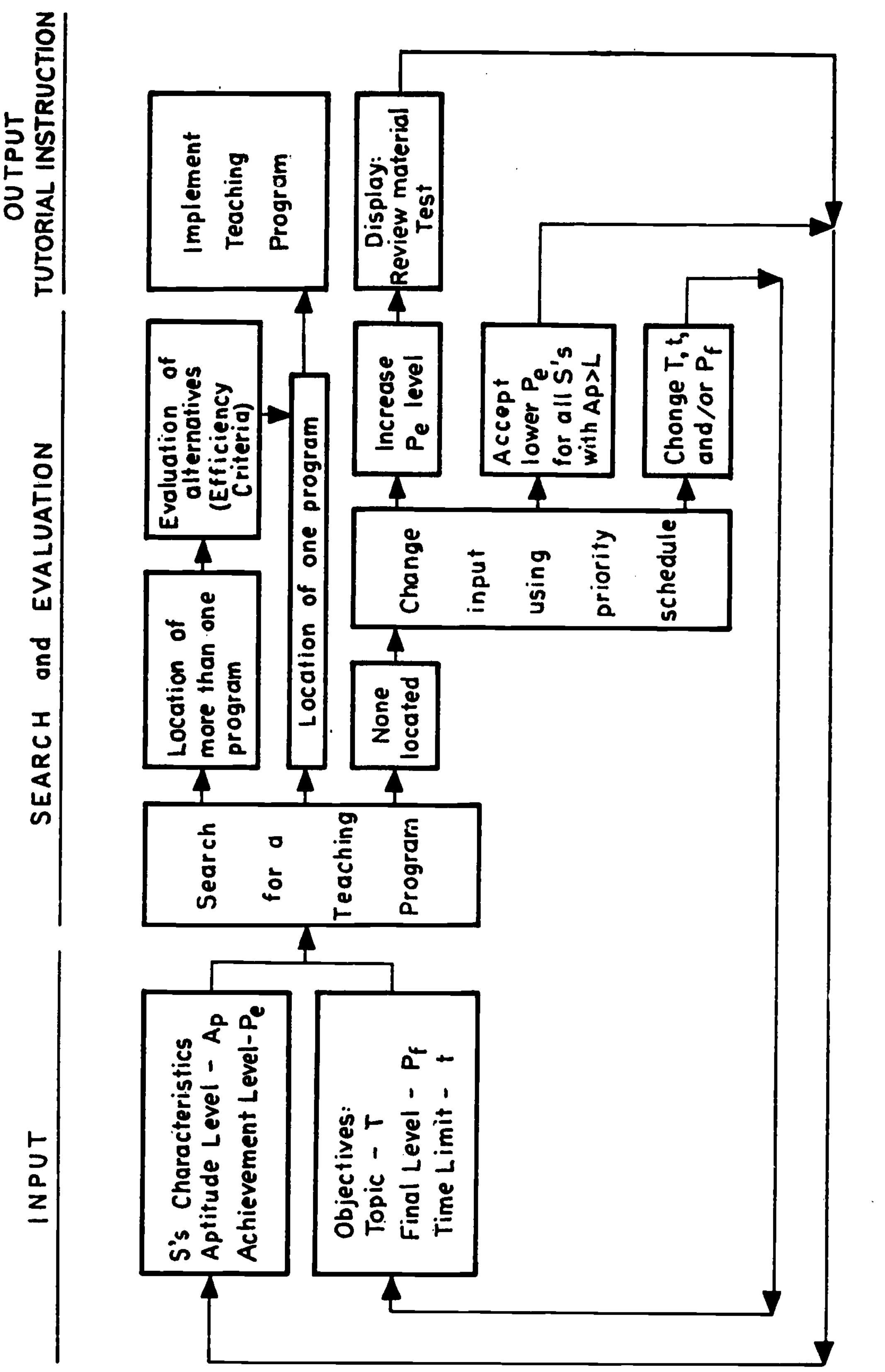

Fig. 1 - Pretutorial decision process (from L. M. Stolurow «Model the Master Teacher or Master the Teaching Model». In J. D. Krumboltz Ed., *Learning and the Educational Process*; Rand McNally, Chicago, 1965).

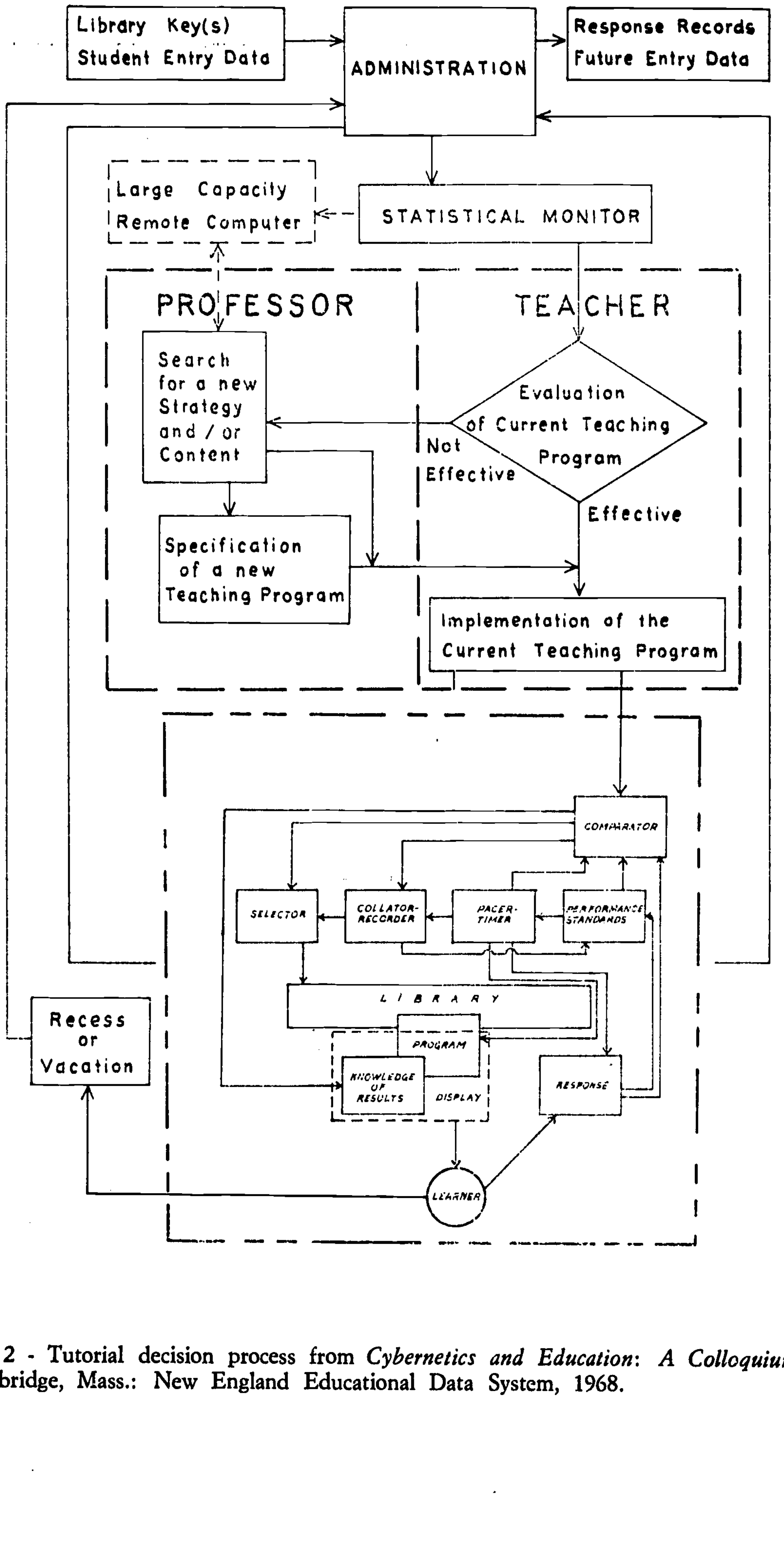

Fig. 2 - Tutorial decision process from *Cybernetics and Education: A Colloquium.* Cambridge, Mass.: New England Educational Data System, 1968.

program he gets.
In an instructional system that uses the idiographic model of programming, it should be possible to use any or all of the following characteristics of the student in a contingency statement or teaching rule: (*a*) aptitude scores; (*b*) personality test scores; (*c*) reading rate; (*d*) knowledge about prerequisite information; (*e*) immediate and delayed retention span; (*f*) reinforcement; and (*g*) preferences. It should also be possible to base decisions, at least in part, on: (*a*) the response to the last frame; (*b*) the responses to a set of other related frames; and (*c*) the response latencies. Additionally, it should be possible to use any, or all, of the demographic information about a student depending on performance characteristics of the learner and/or the part of the program he is studying, and it should be possible to vary from time to time the specific student characteristics used in making decisions.
It should also be possible to vary the decision rule at each branch point, depending on whether the student's performance did, or did not, fall within certain bounds of accuracy and/or latency. This would make it possible to change any rule, or set of rules, during the course of instruction, depending on the student's response history. This is the «Professor» function in Fig. 2.

Some Requirements for Decision Models that Individualize Instruction

It is assumed that the purpose of an adaptive instructional system is to optimize instruction by using the most pertinent and useful information. This means that the instructional system should be designed to provide not just one, but many, programs of instruction. Consequently, the model of such a system differs from one that is not designed to be optimal. It must: (*a*) raise the performance level of as many different types of students as possible; (*b*) in as short a time as possible; and (*c*) at as small a cost as possible.
To do this, an instructional system should be able to present only that information needed by each student to perform according to the terminal objectives. This means it must be selective. Second, it

should be able to present each student with that sequence of information blocks that best suits his particular needs. This means it must be capable of organizing materials. Third, it should be able to select the rate of presentation that suits the student's information-assimilation rate (currently poorly estimated by aptitude tests). This means instruction must be capable of pacing, or being paced, at different rates.

A basic decision to be made in developing an instructional system is whether to design it to individualize means, or ends, or both. A basic question in teaching is whether all students should meet a single set of objectives, or whether each student should meet a different set. Should all students be taught in one way or should they be taught in different ways?

Means/Ends Confusion

A common confusion in discussions of instruction is between the individualizing of means and the individualizing of ends. Currently, we individualize ends and simply restrict the variation in means. CAI provides us with rich possibilties for individualizing the means of instruction. However, varying the means does not necessarily individualize goals, or objectives. In fact, since our attention today is focussed more on the deficiencies of the educational establishment than it is on its accomplishments, CAI is most often viewed as a means by which a maximum number of students achieve a minimal set of objectives. However, CAI also can be used to maximize the achievement of each individual student, which is the maximization of objectives, or ends.

Whether we want to maximize means or ends has significant implications for the nature of teacher training as well as for the design of CAI systems. Stolurow and Davis (1965), for example, pointed out that if students are really different when they begin instruction, and the desire is to make them all achieve the same goals, then the instructional system must be able to provide a different program for every student. In other words, to produce performance changes so that all students attain the same set of objectives it is necessary

to provide as many different teaching programs as there are different levels of entry behavior. If more objectives are acceptable, then fewer instructional programs are needed, but many still may be needed. This means that if we want students to achieve a single set of objectives, we need to train teachers to teach in a variety of ways, and correspondingly we need CAI systems that are programmed to provide a variety of teaching strategies.

Sampling and Sequencing

The two basic problems confronting an author are those of *sampling* the materials to include in the program and of *sequencing* the set of materials sampled. The objectives determine the limits of the sample to be included for all possible students. No one student is presented with all the material, however. The decision that determines just what material to present to a particular student is based upon his performance on a pretest. Those objectives on which he demonstrates proficiency in the pretutorial stage are eliminated from the course. Other information about the student determines the order in which the material is presented.

Instructional Elements

The basic display unit of a program is called a frame. It contains one step of a program. A step inclused some text that informs the student about a concept, a fact or a procedure he is to follow. Illustrations may be associated with a frame, and each frame has a problem or question to which the student must respond. Not always presented to the student but a very necessary part of course development, are the various performance standards that determine what happens when the student responds in different ways. Each response is followed by information about the correctness of that response. This is called knowledge of results, but it is only one aspect. It may also be either a real or a symbolic consequence of the student's action. Included in the feedback may be information that evaluates the last response, or set of responses. The system may also provide

activity reinforcement through contingency management; it may branch a student to a game. These elements of instruction are some of the units with which we must work to develop rules or concepts that permit the separate, or joint, manipulation of each event in ways that optimive a student's performance. These rules also can be called organizing rules; they are the rules of an instructional grammar. Eventually we should develop generative grammars for instruction.

Planning Instruction

Instruction always has an organization, whether we plan it in advance or simply let it happen. Even the latter approach, as free as it may sound, is not a completely open-ended condition. It is important that it appear to be open-ended, but the appearance should not be mistaken for the fact.

Instruction is determined by constraints that exist within the subject matter itself. The number of possible variations is finite and the instructor's own knowledge, skills and interests allow only some of the possible variations to take place. My intent is not to degrade the «let it happen» approach, but rather to put it in proper persepctive. The apparent spontaneity of the approach is an important factor determining student motivation. Therefore, it seems to be a useful characteristic of a system designed to individualize, or personalize, instruction. The problem, then, is to make CAI instruction unfold in an apparently spontaneous way.

One thing that seems to be useful, if not necessary, for developing spontaneity is to plan possibilities, rather than specific paths. This means that a program designed for teaching with a «let it happen» approach requires a different kind of planning from that used in the technology of programmed instruction (PI). PI made the development of instructional materials akin to a procrustean bed, and the game of the theorist and program developer one of demostrating the superiority of one particular bed to all others. Apparently it made little different that the legs of the victims often had to be stretched or cut off in order to fit. Most instruction does this. It was not

invented for programmed instruction. However, we should be interested in fitting the instructional experience to the student. Therefore, we must reexamine our concepts and approaches to instruction. We need greater flexibility. With a CAI system this can be provided by different approaches, such as artificial intelligence. To achieve variety in our instructional means we must learn how to use the flexible logic and large random-access memory of a computer.

Plan Contingencies

A teaching system, either a man, a machine, or a combination of the two, is a mechanism for implementing decisions. The number and types of decisions vary, but an even more fundamental difference lies in the objectives of the teaching programs with respect to adaptivity and the ways they try to achieve it.

Non-adaptive, or response insensitive, teaching systems are those that carry out a set of predetermined decisions made independently of the student's response. In non-computerized instruction, i.e., films, ETV programs and audio tapes, the instructional sequence is fixed, as well as the time allowed for each part. Books and self-instructional programs allow the student to spend as much time as he wants on part of the materials, individualizing his rate of progress. However, the material is not personalized since all students receive the same instruction.

Planning the contingencies that make up an instructional logic, or strategy, is a critical but not a highly developed process in teaching. In fact, except for Ruleg (Taber, 1965; Evans, 1962) and Mathetics (Gilbert, 1962 a, b), this problem has gone relatively unattended. Even with the commitment of programmed instruction to problems of sequencing, we are lacking good guidance. The state of the art, not to mention the science of sequencing, is very primitive and provides no substantial data base from which inferences might be made. There is a critical need for data revealing the effects which different concepts of sequencing have upon rate of learning, retention and transfer. Even when sequencing studies are done, they typically compare an «organized» or «logical» arrangement with a random arran-

gement, but the most superficial examination of a course reveals that there is always more than one «logical» organization. Consequently, we need ways to describe the alternatives and we need to identify some useful variables. One overpracticed approach to this problem has been to treat the organization of a set of materials as the result of applying some rules to generate the sequencing. When looked at in this way the problem is to identify the most effective rules in terms of measures of student performance such as rate of learning, degree of retention, or amount of transfer.

A teaching system that is capable of branching utilizes some aspects of a student's performance to determine the nature of subsequent events in instruction. This type of system is designed to provide a set of possibilities, not all of which will be experienced by a learner who interacts with the system. All of the possibilities are alike in a general, but not in a specific, way. They are alike in their intention to enable students to achieve an objective. Each is designed to provide the learner with what he needs to know and do in order to satisfy a minimal set of instructional objectives. In this type of system the kind of instruction a learner receives is not known until he receives it. It can only be known and described after the course has been completed. What is known before he starts is the set of possibilities he can experience. With a sophisticated system, the set of possibilities is very large and may not be finite. In effect, because of time limitations, the system does provide a finite set of experiences to each learner, but there may not be a way of determining even the number of possibilities in advance. We can refer to the process that produces a student's sequence of materials as the unfolding of his instructional sequence. ELIZ3 is an example of a programming system that works in this way (Weizenbaum, 1966; 1967).

One way of unfolding the optimum instructional experience for a learner is to select the elements to use at each point in time from among a set of possibilities that the system provides. This can be done by formulating contingencies to control the process. These «if... then» statements determine the branching the system accomplishes. This is different from the minimum level of branching which uses the last response made by a learner to determine the next frame

displayed. Crowder (1958; 1959), for example, has described this method as «intrinsic programming». Intrinsic programming builds a program by generating one of a predetermined set of paths. This procedure is a good one for handling sequencing problems with a printed book or film transport device, but more adaptive sequencing is possible.

Contingency Analysis and the Management of Learning

It is important to distinguish between branching and contingency instruction, or response-produced organization. If teaching is described in terms of contingencies, the process can be a response-organized instructional experience. To do this the teaching system must be designed to handle different sets of contingency rules, and it is important to have the system capable of using different ones and of recording which ones are used. Three classes of variables appear to be involved in developing contingencies: (*a*) *who* is being taught; (*b*) *what* is critical; and (*c*) *how* the teaching is to be done. Examples of contingency rules are the following:

Example 1: If the child's IQ is between 60 and 80, and he is learning to read isolated words, then it is critical to require drill and practice in which a high degree of overlearning is provided by initially using prompting, but briefly, followed by a longer confirmation series (Stolurow, 1964).

Example 2: If an American student is high in aggression and makes incorrect responses in learning logic, then in tutorial instruction when he performs incorrectly, evaluate his responses when you tell him he is wrong; when he makes correct responses, simply tell him he is correct without evaluating his response (Frase, 1963).

Example 3: If a student with high mathematical aptitude begins to respond more slowly (longer latency) as he works out the solution to problems that are equivalent in difficulty, then give him additional problem-solving practice but shorten time allowed for solution.

The «if» statement in each example contains a particular characteristic to identify the student. In the first, «IQ» (general intellectual

ability) is used; in the second, a personality characteristic, «aggression», and a cultural index, «American»; in the third, a specific aptitude, «mathematical». Each statement also specifies the critical element of the instructional material or experience. The first uses reading of isolated words; the second, logic and correctness of response; the third, speed of problem solution in mathematics. Each «then» statement includes a direction about how the instruction is to be conducted. In the first example, a high degree of overlearning and confirmation procedure is to be used; in the second, the use of evaluative feedback for incorrect response and the absence of evaluative feedback for correct response; in the third, the period of time allowed for solution is to be shortened.

Individual statements of contingencies that are useful in teaching define a significant set of relationships among exemplars of the three classes of variables just described; namely, who, what, and how. In developing a program, the use of a set of contingency statements defines a *teaching strategy*; each contingency statement is a *teaching tactic*; these terms are interchangeable with teaching logic and teaching rule. These terms and the contingency form can be used to describe either the intuitive performance of teachers or the explicit plans of teachers and authors of programs. The former describes its use for a prescriptive purpose; the latter illustrates its use for a generative purpose. In a sense, the intentional and intuitive labels refer to two sides of the same coin. The prescriptive use of contingency statements is actually hypothetical because the description is in the form of an «as if» statement: the teacher behaved «as if» he were using a set of contingencies as a plan and, therefore, «as if» he used a contingency rule in generating his teaching behavior.

Contingency analysis describes a process; it does not deal with the product of teaching, which is a change in the student's behavior. The process is designed to get the student to achieve some objective he was unable to achieve when he started the program. At the level of the individual student, we need to develop a conception of the interaction process as a cybernetic system of instruction. One purpose is to provide the teacher with information in the form of a history of student responses and his performance on tests. These two sets

of data provide evidence of the success of his teaching methods and give him a basis for making adjustments to improve results.
The three examples of sequencing rules represent a set of primitives, or elements, in a CAI system library. They would be used for teaching and another type of rule would be used for making decisions to change the teaching rules. In order to understand the process of changing sets of rules it is useful to consider the different classes of learning tasks and the modes of instruction. Here the system needs to monitor past performance whenever a rule is used so the rule can, in turn, be related to an expectation.

Classes of Tasks

Six general classes of tasks can be identified, based on the interrelation of input, output and response time. Output can either be greater than (production), less than (reduction) or equal to (conservation) input. Each of these three variations can be combined with the requirement to respond either immediately or after a certain period of time. This results in six classes of tasks, each presumably mapping on a matrix made up of rules, or contingency statements, which need to be based on research findings.[1]

Modes of Instruction

The following five basic modes of instruction identify patterns of use that can satisfy a requirement for a «then» statement in CAI: (*a*) problem-solving; (*b*) drill and practice; (*c*) inquiry; (*d*) simulation and gaming; and (*e*) tutorial instruction.

Problem-solving refers to the use of a computer to solve quantitative problems and the student uses a language like FORTRAN or BASIC to accomplish his purpose. He writes a program and enters his data. In this mode the computer is used to do what it is primarily designed to do. Little special systems programming is required.

[1] A learning task is one in which the learner proceeds from inability to perform one or more specified acts under defined conditions to the ability to perform them at a measurably greater level.

Drill and practice is the use of a computer to present learning materials such as spelling drills and problems in arithmetic which utilize the same sequence and format to give a student repeated opportunities for response. The student uses his natural language and the objective is to build skills.
The inquiry mode is often called information retrieval. In this mode the student uses a natural language, as he does in the drill and practice mode; he forms questions which he addresses to the system. The system typically processes the questions using key words and search algorithms to retrieve an answer. In simulation and gaming, the student also uses his natural language and is given options to use in deciding what and how to vary the input; the system quickly reports the consequences of his decisions. Models used for processing the student's responses vary in their corresponse with specific exemplars of the class of event systems that is modeled, e.g., a business. Usually it is the logic of the game that is its critical characteristic. In simulation the input and output correspond highly to a real situation.
Tutorial instruction is a level of instruction that not only involves dialogue but also the other modes. For example, the consequences of a student's response to a question may be drill and practice, or it may be a game, etc. In short, the other modes become classes of instructional experience that can comprise the «then» statement of a contingency rule. Within instructional modes, a number of variations are still possible, so an algorithm is used to select not only the mode of instruction but also particular variations to use within it. To locate within a mode the particular variation that is wanted, there have to be contingency rules that depend upon who the student is and how he has performed. This mode can be looked at as a form of artificial intelligence.

Some Examples of Instructional Programming to Support «Learning How to Learn» Skills

The following are some primitive examples of programming designed to ultimately achieve the level of sophistication that is desired in

personalized, or idiographic, programming. They are presented simply to describe the present state of this primitive art. The objective is to develop system capabilities which maximize the emancipation of the learner from the level of being «teacher-taught» to one of being «self-taught». The following examples serve to illustrate how a system can be programmed to create a more adaptive learning environment for students.

A Study[1]

In the study to be described the consequences of using a particular rule of adaptive instruction were examined. A program to teach students to make decisions about the validity of syllogisms was developed and used. The contingency rule was the following:
If the student's speed and accuracy in making each one of a set of decisions reveal that his optimum strategy is to make these decisions in a particular sequence, then to get him to discover and consolidate his optimum strategy, have the system present a new set of problems proportioned to conform to his optimum strategy. For example, assume in making a decision with Rule A his speed was (S_a) and accuracy was (A_a) and with Rule B it was (S_b) and (A_b), and so on for the four rules. Then by using the method described in Detambel and Stolurow (1956) and Stolurow, *et al.* (1955) his optimum strategy would be determined. It may be to use the rules in the sequence CABD. Having determined this for one set of syllogisms the system could proportion the new set. This rule was used in a learning environment provided by a CAI system. The students were to «discover» their optimum strategy and consolidate it. Also, making decisions about the validity of a set of syllogisms is not a task in which there is one «best» strategy in the sense that every student should use the rules in one and only one sequence. An optimum strategy in this type of learning task is one that uses the four rules in a sequence that depends upon the individual student's proficiency in applying the four rules. The set requires that the four rules be

[1] Jack Odel assisted in this study.

used and all were displayed to eliminate retention as a variable. The question to be answered in the study was whether students would, in fact, use their own optimum strategy when the conditions for each of them to do this were idealized; the system adapted itself to each student's past performance. For example, if the student's optimum sequence was found to be CABD on the first set, then the system composed a second set of syllogisms in which Rule C was violated most often, Rule A next often, B next, and D least. This is an example of adaptive instruction; it involves matching of subsequent experience to the student's response preferences and skill in using rules.

In this study students were taught to use the four rules stated in Table 1 in making their decisions. They were given an initial set of 40 syllogisms, ten of which violated each of the four rules. They were given the syllogisms one at a time and had to decide if they were valid. To do this, they picked a rule and determined whether the syllogisms violated it. If not, they tried another until they found a violation or that the syllogism was valid. Each use of the rules, in terms of the time the student took and the errors he made, was recorded by the system. A sequence of usage is used here to define a strategy. The frequency of usage of the 24 possible strategies is summarized in Table 2; it shows that only 13 of the 24 were used. Based upon each student's data on the first 40 syllogisms, the CAI system computed his optimum strategy in terms of the order in which he should apply the rules so as to minimize, on the average, the time he would take.

The results are presented in Fig. 3. It shows that the students did not use their optimum sequence in the second set of 40 syllogisms. In fact, they averaged about 70 percent deviation from optimum. After each block of 14 trials the students were asked to report their recollection of the order in which they used the four rules, and their answers were compared with their actual record to get an awareness measure. These data (Fig. 3) indicate that without specific instruction on strategy, the students were more aware of their immediately preceding response pattern than they were behaving optimally. However, their recollection of their performance was not very high.

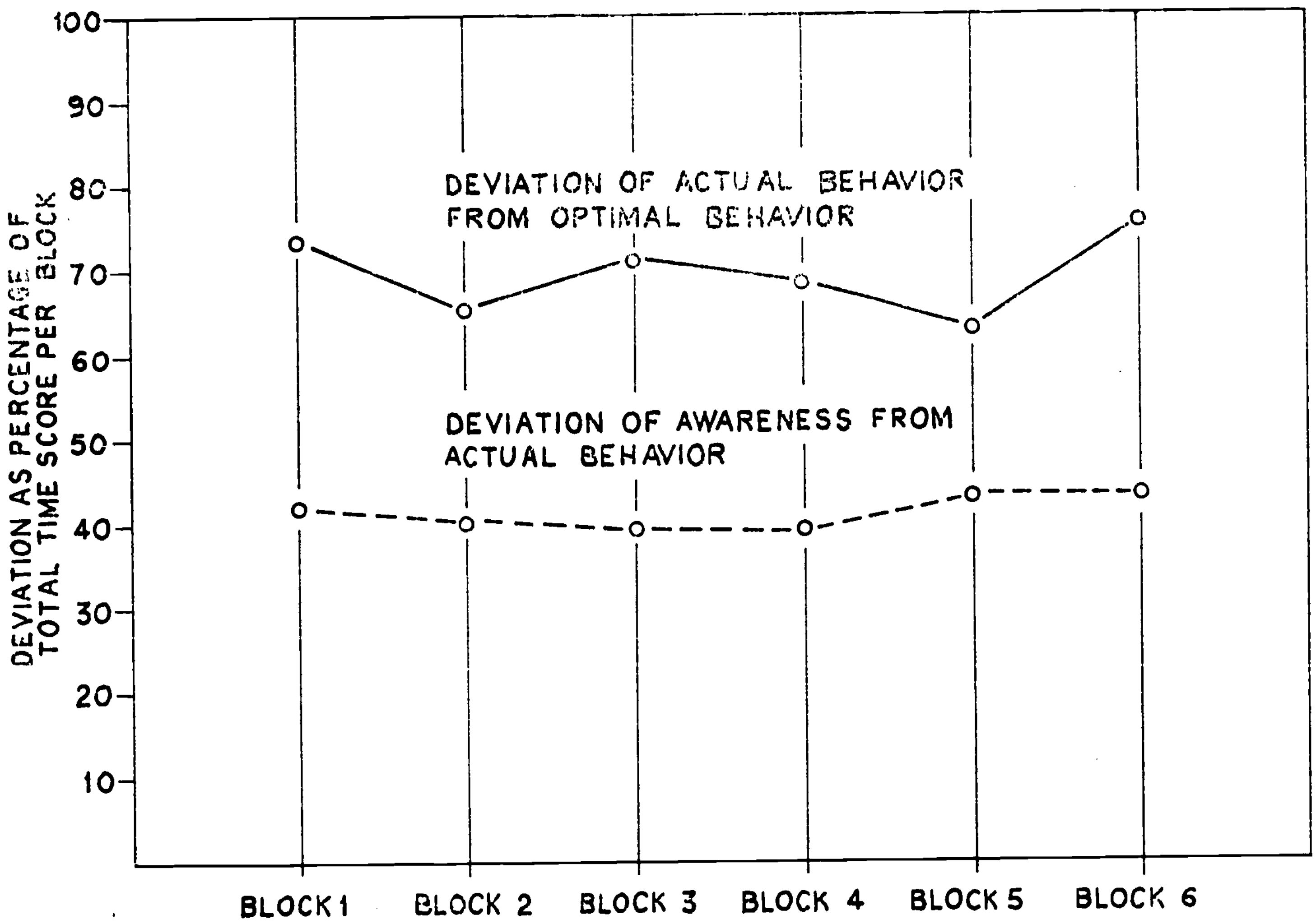

Fig. 3 - Deviations of actual performance from optimal strategy and awareness.

Table 1
Information panel given to students while judging the relevance of each of the rules.

RULE A
The middle term must be distributed at least once in the statement of the syllogism.

RULE B
If a term is distributed in the conclusion, then it must be distributed in the premise.

RULE C
A valid syllogism cannot have two negative premises.

RULE D
If either premise is negative, the conclusion must be negative.

CONDITIONS GOVERNING DISTRIBUTION
1. Universal propositions distribute their subject term; particular ones do not.
2. Negative propositions distribute their predicate term; affirmative ones do not.

One hypothesis suggested by this study is that students need explicit instruction about decision strategy so they can optimize their sequence. When left to himself, a student does not discover his optimum procedure. A CAI system designed to provide the tutorial mode of instruction and also capable of «Professor» behavior (Stolurow and Davis, 1965) could respond to data like those shown in Fig. 3 by branching a student to explicit, tutorial instruction about strategies in using a set of rules in an optimum order. In the idiographic model of CAI (Stolurow, 1965 c, d) the Professor function would change the rules of teaching if the student's performance indicated that this was desirable. In this case, the CAI system could present to the student both his time and error scores in applying each of the four rules by typing a summary table after blocks of syllogisms.

Table 2
Frequency of use of strategies.

There are 24 possible sequences which can be used in evaluating the presented syllogisms. Only 13 unambiguous sequences were actually used. This was determined by the criterion test explained earlier. The 13 sequences which actually occurred and their frequency of occurrence are listed below.

	Sequence	*Frequency*
1	CDAB	63
2	CDBA	51
3	CADB	11
4	ABCD	7
5	DCAB	6
6	ACDB	5
7	CBDA	4
8	CABD	3
9	DCBA	2
10	ACBD	2
11	CBAD	1
12	BACD	1
13	BCAD	1
		157

Then it could change to a directed discovery mode, for example, to teach him to work out his best strategy, based on his past performance. Following this it could give him additional syllogisms for decision so that he could get practice in using his optimum strategy; this part of the instruction could be in the drill and practice mode.

Some Techniques to Aid Individualization

There seems to be a prevalent misconception that CAI does not have

the ability to allow students to learn how to learn. Some features of the CAILAN programming language on our IBM 360/50-based CAI system will be described to indicate some of the beginning steps taken to achieve this objective. The following figure (Fig. 4) shows the instructions that tell a student how to take notes for himself. With this option he can record his own behavior over a series of problems, such as deciding upon the validity of syllogisms, or he can record formulas displayed on the slide projector that he wants to study later on. While processing for the course being taught the system ignores these notes but records them, both on the «hard copy» produced at the typewriter which the student can take with him when he leaves and internally, for later use by the author or teacher. The author can request a printout of the internal record for his own use, if he wants to look at it. A special program has to be written to extract this information from the raw student records, however.

Figure 5 shows Dr. Hellerstein, a pathologist and one of our authors, at an audio-visual console. When the system is used in the student mode for his course a medical student would sit at the console. In this CAI program the second-year medical student sees transparencies made from glass slides used in the histopathology laboratory. They are shown at each of a series of progressively greater magnifications and for as long a period as the student likes. Then one level of magnification is shown and the student is asked questions about each slide he views. The student is given appropriate feed-back as he responds, and is branched to different parts of the course, depending upon his response. This brief and general description of the dialogue provides some background for the description of an error-correction rule which the program uses. The rule states that if the student mistakes one slide for another, Y for X, he will be shown the one he misidentified, Y; he will be told he made a mistake and asked to study slide Y. Then he will be asked to distinguish it from slide X, which will be reshown, and he will be asked to correctly identify the disease and organ represented by slide Y. In this example (see Figg. 6 and 7), the student first looked at a 200x slide of candidiasis but identified it incorrectly as mucormycosis. He is the-

refore shown a slide of mucormycosis and told to examine it carefully and compare it with the previous slide. When finished looking at what the thought it was, he presses the EOB key.[1] This contingency rule is used to support the instructional objective of teaching students a «learning how to learn» skill. In this course they need to learn how to identify diseases and organs from slides. This is a perceptual learning problem and while successive discriminations are not as efficient as simultaneous ones, they are used here as a first level correction procedure. If the error were not eliminated, then a simultaneous discrimination procedure would be used.

Fig. 4
Instructions for note taking procedure.

If during this lesson, you want to take notes or make comments that the computer should not process as answers to its questions, follow this procedure:
1. Type ### (three cross-hatch marks)
2. Then type your note or comment (lenght limit: one line)
3. Press EOB
4. For more lines of comment, repeat 1, 2, 3 above.
5. When finished, answer the previous question.

Example:
What is the function of a «wa» code in AMD Coursewriter?
see coursewriter manual, U. Texas
see also use of wa in E. E. Hellerstein's pathology programs follows qu, if a match all minor op codes are executed, then loops back to wait for another answer
Correct. Look at the example on your screen.
If there is a wa match, list the codes that will then be executed.

[1] EOB stands for End of Block; it is the key which the student always uses to tell the computer he has finished his response.

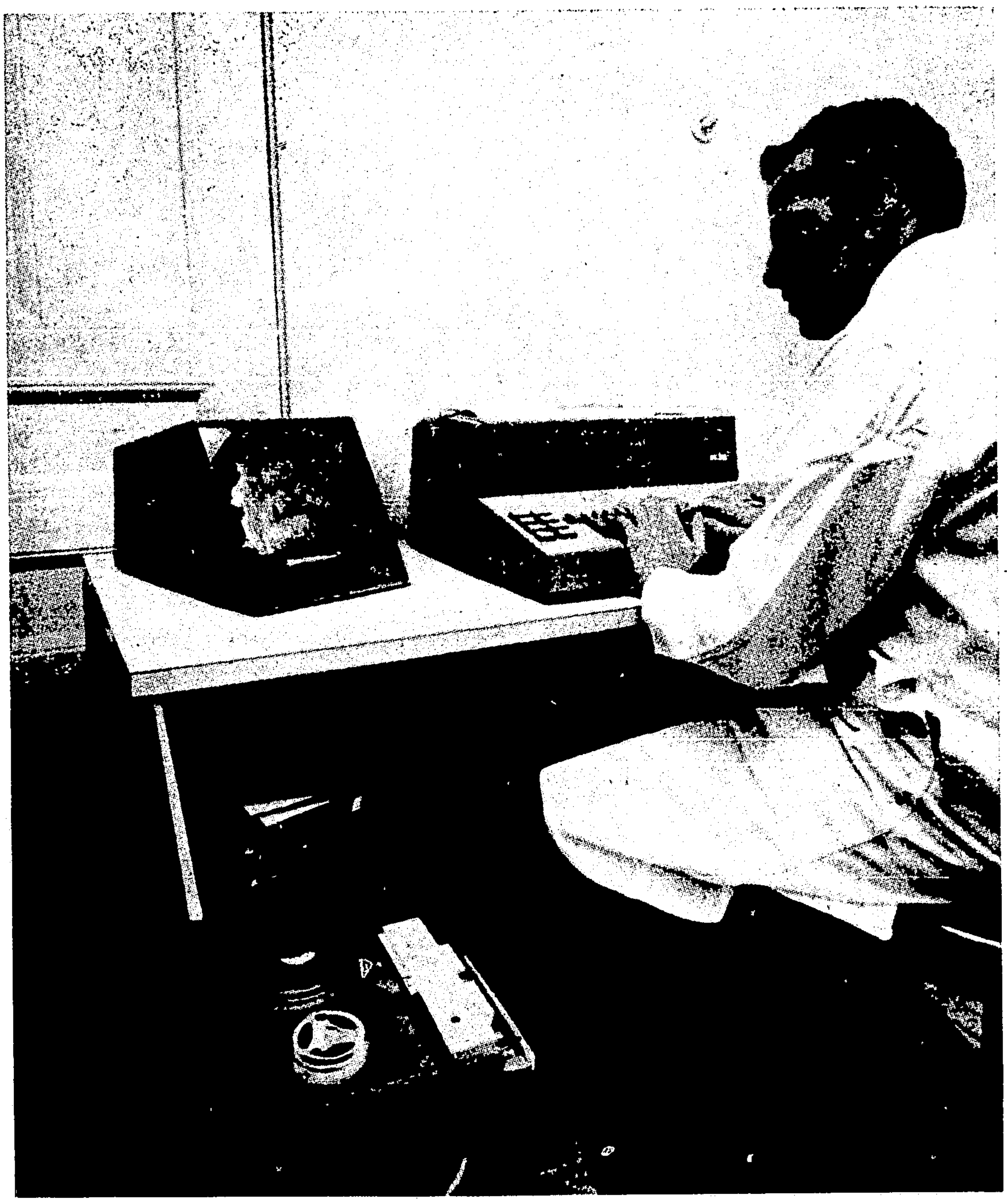

Fig. 5 - Dr. Earl E. Hellerstein, Assistant Professor of Pathology, Harvard Medical School and Associate Pathologist, Peter Bent Brigham Hospital, Boston, Massachusetts seated at an IBM 1050 audio-visual console in the Harvard CAI Laboratory.

Fig. 6 - 200x slide of candidiasis used in CAI course in pathology.

Fig. 7 - 200x slide of mucormycosis used in CAI course in pathology.

At any point in the program the student can voluntarily request any slide. The listing in Fig. 8 describes the procedure he can use to do this. This set of instructions comes from a program in economics which also is on our CAI system.[1]

Fig. 8
Instructions for voluntarily requesting a slide.

At any time during this course, you may request that a table or figure be shown (on the screen at your left) simply by typing in the table of figure you want:

table 5a

You may practice this technique now if you wish.

figure 3

Press EOB when ready to go on in the course.

Just by looking at Table 2, is it possible to determine whether Magnate's production function is a fixed proportions or a variable proportions production function?

table 2

Please answer the question.

yes

What kind of production function does Magnate have?

variable

Correct. He has a variable proportions production function.

[1] The Harvard CAI system is a multiple access student system with an IBM s360/50 CPU. It uses audio-visual IBM 1050 consoles (see Fig. 5), some of which have a 320 slide capacity.

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